Information Management on Future Navy Ships

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ABSTRACT

This paper discusses issues facing information technology (IT) system developers for Navy ships. Its overall emphasis is on the management of large volumes of tactical information that a ship must collect and process during its missions. Specifically, it describes a very ambitious notion of a future Navy Comprehensive Information Management System (CIMS). Challenges and solutions are suggested for CIMS implementation. Many technical areas of information technology are covered as a set of recommendations for future Navy information systems rather than as an analysis of problems for a particular application. Whereas they reflect the Navy's current and projected needs, many of these recommendations will be possible to achieve only with significant breakthroughs in technology and its applications. Therefore, this paper can serve as a challenge to researchers, engineers, and technology developers in government and industry to find solutions that meet future IT requirements of naval vessels.

INTRODUCTION

Because of its unique capabilities, the U.S. Navy is the primary service to achieve forward-deployed power projection as a means of protecting national interests. In the platform-centric warfare of the past, naval commanders were concerned much more with how to manage the weapons and sensors capabilities onboard their own ships and the information they could acquire than with the total tactical picture of the theater. The main reasons for this were lack of sufficient bandwidth for communications and a lack of technology to fuse, integrate, and display information rapidly. We enter the new millennium with the emphasis on information as an important resource, a condition evident in the current military trend toward network-centric warfare. Enabled by modern database management, networking, and user-interface capabilities, network-centric warfare [1] implies that all platforms in the theater are aware of and contribute to the total information available to all ships, aircraft, and ashore command centers. In some circumstances, a commander could even deploy assets based on another ship.

Network-centric warfare [1 and 2] also implies that the volume of the information available to warfighters on a theater-wide basis will keep growing. This, in turn, also necessitates that engineers provide to Navy commanders a Comprehensive Information Management System (CIMS) that includes the current capabilities of tactical and non-tactical systems. A CIMS also must feature the next-generation technologies that are now the subjects of intensive research and development efforts in the Department of Defense in general and in the Navy in particular. CIMS is not a formal Navy program; rather, it is a generic term to indicate what is expected to evolve over the next decade and beyond.

The challenge facing Navy planners and administrators is how to accomplish this in an atmosphere of cost cutting, limited budgets, and reduced resources. Whereas past military systems relied mainly on specially built equipment that conformed to military specifications, today's Navy and that of tomorrow will feature a greater usage of commercial off-the-shelf hardware and software. This trend will enable not only cost savings but also the use of new products and services of industry to maintain the leading edge in technology for the warfighter. (See, for example, [3]).

Also consistent with the policy of cost savings, next-generation Navy ships will have fewer personnel. Sailors will need to learn multiple jobs

and become familiar with multiple tasks, in addition to what they are doing today. This implies that more automation will be necessary in all areas, especially automation in training systems, such as Web-based training. More than ever, tomorrow's Navy will learn how to accomplish more with fewer resources.

CIMS CAPABILITIES

The ideal CIMS will provide the following capabilities and address the following topics:

- Database integration and knowledge-base integration
- Knowledge-base integration with databases
- Database and knowledge-base standards and refresh for these standards
- Maintenance of security during database integration
- Data standardization to facilitate database and knowledge-base integration
- Data warehouse technology and data warehouse software refresh
- Data preprocessing and cleansing prior to storage in data warehouse
- Data mining that includes mission-directed Web searches
- Data-mining tool refresh
- Enhanced data-fusion technology
- Advanced data storage systems
- User-friendly database and knowledge-base access
- Database and knowledge-base management, including correct database management system (DBMS) and knowledge-base management system selection and refresh of commercial off-the- shelf and government off-the-shelf and software
- Regular updates of standard command and control systems, such as the Global Command and Control System–Maritime (GCCS–M) [4] and the databases that support them
- Periodic assessment of data storage requirements and plan to meet future needs
- Use of intelligent agents in conjunction with data warehouse, databases, and knowledge bases
- Knowledge- and data-replication to avoid a single point of failure
- Subsystem to provide situational awareness
- Computer network information on all offensive efforts
- Information-service "reach-back" to networked ashore capability
- Information warfare activity integration
- Integration of intelligence and security information

CHALLENGES AND SOLUTIONS FOR CIMS IMPLEMENTATION

The Navy must overcome many obstacles before the completion of a CIMS. This section describes some of these obstacles and challenges [4] that Navy information systems engineers will encounter.

Data Fusion

Naval forces need to link and fuse in real time more sensor data from a wide variety of sources. This implies a requirement for a modular, open-systems environment in which various data fusion engines can be inserted or deleted. Meeting this requirement necessitates an unprecedented data

fusion effort for sensors on aircraft, unmanned airborne vehicles, satellites, and precision weapons of all U.S. and allied forces. The Navy will fuse information, or will used finished fused data products, from other services and allies in the common operating picture. The CIMS ideally will accommodate any sensor input—a situation that is very open-ended. Therefore, one challenge is for the U.S. Navy to know when this requirement is satisfied, especially when the Navy has no direct control over the interface designs of sensors from the other services and allies. (For more information on the joint vision, see [5 and 6]).

Distributed Database Components

Data will be collected and integrated. For example, the CIMS will contain the biological and chemical sensor information that will be integrated. Engineers will need to develop metadata [7] documentation of database systems components with an explanation of the relationship between components (e.g., how their data elements are subsets or a superset, etc., of the integrated databases) that support major existing systems, such as GCCS–M. Database access efficiency depends on the hardware, the DBMS, the operating system, and the relative priorities of competing tasks. Thus, the CIMS will feature a modernized version of a distributed, federated database. (See, for example, [1, 8, 9, and 10]).

Optimized Data Structure

The establishment of an information warehouse in a data management system for all users is not enough to guarantee an optimized data structure. Therefore, engineers must consider all of the factors necessary to achieve an optimized data structure. Also, engineers must provide to the users (e.g., sailors) an online document that will explain the operations for which the data structure will be optimized. For example, a data structure optimized for retrieval performance will not be optimized for data storage performance and vice versa [11]. The documentation will list the advantages and disadvantages of the particular data structure selected for implementation. This information is generally not present in current command and control database systems in any comprehensive sense.

Data and Database System Standardization

The CIMS will feature data standardization that is needed, not only for sensor-data fusion, but also for other aspects of data integration. The CIMS will contain an up-to-date reference list of all necessary and germane data standardization documents. The Defense Information Systems Agency (DISA) has instituted the Defense Information Infrastructure Common Operating Environment (DII COE) as an essential element for inter-service interoperability [4]. The DII COE includes the Shared Data Environment. The CIMS will comply with DISA's standards at each level of DII COE.

Data Aggregation

The CIMS will provide access to distributed legacy databases through a user interface, which is a step toward data aggregation. However, this is insufficient to guarantee uniform data services to all active components. It is only a step on the way to data integration and not data integration in its entirety. The challenge that the Navy faces here is to determine all steps in the information integration process, including data aggregation and addressing any security implications that this aggregation creates [4] on a resources-available basis.

Information Integration

Information Integration Analysis

Extensive analysis is necessary to integrate and present clear and non-redundant information. The Navy will face the challenge of ensuring that the CIMS will be based on the analyses that have been performed, considering the cost and security implications. The ideal CIMS will use what engineers have learned from others' experiences in information systems integration so it can present clear, useful, timely, and non-redundant information to its users.

Information System Integration Details

The Navy will need to describe and document its integration approach, including how much integration can be completed given the financial constraints. To accomplish a successful CIMS, engineers will need to provide details of how information systems integration will be performed on all levels, including semantic and data levels of integration. The engineers will become familiar with the integration methodology and the algorithms used to accomplish it. A list of integration priorities must be developed because all desired integration tasks cannot be performed in a reasonable timeframe and within budget [12].

Online documentation will describe the database integration strategy and or methodology with enough detail so that personnel who are not computer experts will know that the integration method will result in the required seamless database interfaces and will include integration on all levels. Data residing at different decision centers will not be consistent automatically. Therefore, the CIMS will need to be able to identify and resolve the inconsistencies. (See, for example, [9 and 13]). The integration method and architecture will be specified. The level of integration in the CIMS will be specified so that the user will know what the developers could accomplish at the allocated funding level. Ideally, the CIMS should be integrated on three levels: platform, syntactic (data model), and semantic [9 and 13].

Integration Methods and Large-screen Displays

Large-screen displays are a common feature of modern command centers. Large-screen displays can facilitate error detection on an *ad hoc* basis, but they cannot substitute for a thorough database integration effort. To reduce inconsistencies in the data, more automated methods are needed and specific algorithms should be utilized. The CIMS should provide a description of all integration methods that will be used before giving users a possible means (but not a systematic method) to notice data inconsistencies via large-screen displays.

Data Cleansing

The ability of an information warehouse, a common backbone, and a large-screen display to increase reliability and consistency is only as good as the integration and data cleansing [14] that has taken place in the data sources. This integration and data cleansing must be performed before taking the following steps:

· Installing the data in the warehouse
· Making data available on a common backbone
· Displaying them on large-screen displays

Ideally, only clean and consistent data will be stored in the information warehouse. However, few if any databases of appreciable size have ever had totally clean and consistent data.

Information Warehouse

In the ideal CIMS, an information warehouse provides a complete source of warfighting information and knowledge to all echelons. To accomplish this, engineers will have to define metrics to evaluate the completeness of warfighting information and knowledge in the information warehouse. They will need to test and evaluate the ability of the information warehouse [15] to deliver information efficiently to the user at each stage of compliance. For example, it may be possible to provide a 70% solution at time, t, and an 80% solution at time, t+x. The CIMS will function best if database administrators load all warfighting information and knowledge into the information warehouse in well-defined stages. A difficult challenge to engineers will be to determine how all data systems will be integrated into a single information warehouse. A common metadata repository must be part of the data warehouse to support the CIMS and the common operating picture.

Knowledge Management

Knowledge Standards and Knowledge Management

Commercial, open-system standards will contribute to an affordable and information system architecture designed to accept upgrades efficiently. Database management services with Relational Database Management Systems and with Object Relational Database Management Systems, such as Open Database Connectivity, are well known. However, standards as they apply to existing capabilities and equipment are insufficient. Because knowledge centricity is an important feature of future ships, the information processing standards will need to include the emerging knowledge standards, such as Open Knowledge-Base Connectivity (OKBC) [16], Knowledge Interchange Format, or Knowledge Query Markup Language [17]. OKBC is the knowledge analog of Open Database Connectivity. Standards need to support open data and information exchange architecture. The CIMS will support this criterion by including the class of standards to address knowledge interchange. The current knowledge standards will evolve to higher levels during the coming decade. Therefore, the CIMS will be evaluated for a periodic refresh of knowledge standards as new ones emerge. These standards will contribute to database and knowledge-base integration, including the integration of ontologies necessary to support future artificial-intelligence technology in the knowledge management system(s) of the CIMS.

Common Ontology

The CIMS will have a common ontology and a knowledge base derived from it that will be accessible to all users over the network. This ontology will be necessary to enable the semantic integration that knowledge centricity implies [17]. In addition to OKBC, a common ontology and the tools to merge ontologies and knowledge bases (of other services and allies) are necessary pieces of the puzzle [16 and 17]. The ideal CIMS will include the complete integration of knowledge bases and databases into a seamless common operating picture. The Defense Advanced Research Projects Agency has sponsored the High-Performance Knowledge Base program, which produced results that can contribute directly to information-systems and ontology integration problems. (See, for example, [16, 17, 18, and 19]). The CIMS also will make a common ontology available to intelligent software agents. The Navy's challenge in this area is to identify the correct ontologies for integration and to include all relevant concepts in the unified ontology.

Data Mining

Data fusion processing and planning processing are necessary but insufficient by themselves to ensure functional knowledge-centric decision centers. Tactical data mining will be a capability exploited on future Navy ships. The CIMS will assist users to perform the steps of data mining to be carried out on each ship. The CIMS also will assist users in determining the desired outcomes of data mining for a particular task and the tactical data-mining tools required to complete the task. The CIMS will integrate the outputs of the intelligent software agents and coordinate the behavior of the intelligent software agents with each other with the output of the tactical data-mining tools to augment the knowledge base. Promising current approaches to data-mining problems [20, 21, 22, 23, 24, 25, and 26] in the area of command and control [20, 21, 24, and 25] range from Bayesian networks for data-classification tasks [21] to knowledge mining with randomization and features to overcome the knowledge-acquisition bottleneck [25].

Mission-directed Data Mining

Although Internet connectivity is common in today's Navy and will be part of the total communications package, a specific need for this type of connectivity has been identified to support cryptologic and information-operations, mission-directed Web searches. The CIMS will enable sailors to implement cryptologic and information-operations, mission-directed Web searches, and to integrate the information obtained from such searches with other data sets already in the database where appropriate [1].

Data-mining Technology Upgrades

Tactical data mining is not a reality today. The whole data-mining process as we know it typically takes too long to be accomplished in seconds and is therefore not yet suitable for tactical, real-time applications. However, in the coming decade, tactical data mining may be not only possible, but tools to accomplish it may be modular, commercial off-the-shelf, user-friendly, and compliant with Department of Defense standards. Therefore, the CIMS will include technology refresh in the area of data mining to enable this new and developing technology to contribute significantly to knowledge centricity.

Information Operations, Efficiency, and Security

Information Operations

The information management and information integration activities will be coordinated with the information operations activities to provide efficient and seamless information services. An ideal CIMS will be able to handle smooth interoperation and conflict resolution between these activities.

Situational Awareness

Situational awareness relates to the common operating picture, the common tactical picture, etc., that will be available to all Navy personnel in the theater. Tactical decision-makers on future ships will have an adequate situational awareness about their operational posture (friendly, hostile, and neutral) in the electromagnetic spectrum, in the computer network environment, and in other domains such as the psychological, cultural, and environmental "pictures." Inherent in this requirement is the need for appropriate decision aids, algorithms, displays, simulation tools, etc., to provide situational awareness in the information-operations arena.

Computer Network Exploit and Attack

A Strike Force Commander must be aware of all offensive efforts that may affect the strike (hard kill or soft kill). The future CIMS will need a specific capability to provide the Strike Force Commander (and other Strike Force Commanders in the theater) information on all offensive efforts to avoid overkill of targets that could cause the unnecessary expenditure of scarce and/or limited ordnance resources.

Reach-back

To reduce the most expensive cost factor (payroll), personnel limits have been specified for future ships, with the expectation that functions can be moved ashore and future ship operators can "reach back" for what they need. To make sure that future ship personnel will have all the information services they need at the same level of reliability, these supporting shore services will need to be more secure, robust, redundant, and capable than they are today. An ideal CIMS will need to meet all of the information system requirements, either onboard the ship, in the theater, or on shore.

Information Warfare Activity Integration

The Navy divides information warfare into two categories: (1) offensive (information attack) and (2) defensive efforts (information protection and assurance). The ideal CIMS will integrate these functions aboard future ships, for both traditional information systems, e.g., tactical communications, message traffic, voice, etc., and those associated with the computer network environment.

Levels of Security

Secure database technology is now available. The CIMS will feature multi-level security (MLS), which will address issues such as MLS vs. network security, network security vs. secure operating system and/or secure DBMS, etc. Security needs to be implemented at all levels to preclude a weak link in the security chain. Network security is not enough. Most of security is enforced on the network in a network-centric security system. The CIMS will provide security at the operating systems and database management systems level.

SUMMARY

The information management systems on future Navy ships will provide rapid access to fused and integrated data and knowledge to meet the ever growing needs of tomorrow's warfighter at sea. The technology now in the research and development stages will make a valuable contribution to enhance the capabilities of our naval and joint forces throughout the coming decades.

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